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A SCHEME FOR NOWCASTING HEAVY RAINFALL FROM MESOSCALE CONVECTIVE SYSTEMS (MCSs)

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1. INTRODUCTION

The National Environmental Satellite, Data, and Information Service (NESDIS) has been involved in operationally estimating precipitation amounts from satellite data for more than a decade. Building on this experience, NESDIS is now developing a Prototype Flash Flood Estimation and NOWCASTING Scheme (PROFFENS). NOWCASTING consists of a detailed description of the current weather along with a short-range forecast for the next 0-12 hours (Scofield and Weiss, 1977). PROFFENS involves the development of techniques for analyzing how much rain has fallen and forecasting (0-12 hours) how much more rainfall will occur and where. Short range forecasting also involves predicting where "new", heavy precipitation systems will develop. Geostationary satellite data is the principal data source for PROFFENS. Since geostationary satellite data is potentially available globally, PROFFENS could be used around the world. Of course, precipitation observations, precipitation estimates derived from radar, surface and upper air observations and numerical and statistical forecast models and guidance products are used PROFFENS. NOWCASTS from this will aid forecasters in evaluating flash flood situations and in the issuance of flash flood watches and warnings. Precipitation NOWCASTS can also be inserted into hydrological models for predicting river/stream flow rates and flood crests. Analytical methods incorporated in PROFFENS are already in use over the USA (e.g., the NESDIS Interactive Flash Flood Analyzer (IFFA)). NESDIS is working to extend PROFFENS to other countries like Taiwan, Mainland China, and Brazil. This paper will briefly describe the components of PROFFENS; a case study is also presented. A more detailed discussion of PROFFENS and additional case studies will be presented in a NESDIS Tech Memo to be published in the near future.

2. A SCHEME FOR NOWCASTING HEAVY RAINFALL FROM MESOSCALE CONVECTIVE SYSTEMS (MCSs)

This NOWCASTING scheme is presented in the form of a decision tree and is illustrated in Figure 1. The scheme is divided into two parts: PART 1 --- the MCS is present and PART 2 --- the MCS is not present. In those situations when the MCS is present, there are four steps to the preparation of NOWCASTS. The following briefly describes each step.

Step 1: Determine Type of MCS Present (Scofield, 1985)

In Step 1, the "satellite type" of MCS is determined. Satellite convective cloud categories have been developed for heavy precipitation systems. These categories were based on GOES satellite (VIS and IR) imagery, radar, rainfall and surface and upper air characteristics. Each category has distinctly different cloud patterns and/or cloud temperature attributes, life cycles, precipitation characteristics and mechanisms which initiate, focus and maintain the heavy rainfall systems.

Step 2: Forecast MCS Propagation (Scofield and Robinson, 1989, Xie Juying and Scofield, 1989 and Jiang Shi and Scofield, 1987)

In Step 2, a 0-12 hour "qualitative" forecast of MCS propagation is produced. This Step involves producing a synoptic/mesoscale analysis. Propagation refers to the movement of thunderstorms as a result of preferred new cell development on one flank (usually on the right or right rear) of the updraft. Propagation occurs as the result of the storm's interactions with an environment possessing potential buoyant energy and moisture convergence; low level equivalent potential tem-

KP

90

perature (theta-e) analyses and NGM 6 to 12 hour forecasts of moisture convergence are important parameters for assessing these interactions. MCSs move in either a forward or a backward direction. Forward propagating MCSs are defined as ones that have an eastward component (NE, E or SE); backward propagating refers to a westward (NW, W or SW) component of movement. Sometimes MCSs regenerate and pass over the same area for a 6, 12, or 24 hour period. Scofield, et al. (1990) have shown that backward propagating MCSs are responsible for many of the major flash floods that produce eight or more inches of rain. Satellite, surface and upper air features associated with forward and backward propagating MCSs and regenerating MCSs are presented in the references mentioned in the beginning of Step 2.

Step 3: Compute Rainfall Estimates

In Step 3, rainfall estimates are computed from the satellite data. Of course, observed rainfall and radar estimates will be used in the analysis of rainfall. Knowledge of "how much rain has already fallen and where" is a necessity before the 0-12 hour Quantitative Precipitation Forecast (QPF) (Step 4) can be produced. There are two techniques for computing rainfall estimates; one technique is automatic, the other is interactive.

Convective - Stratiform Technique (CST)
(Adler and Negri, 1988 and Lyles and Scofield, 1989)

This automatic technique, called CST, provides a "First Guess" rainfall estimate that alerts a meteorologist as to which MCS is producing the heaviest rains. The CST has 3 Steps: Step 1: the coldest temperatures in the IR data are located, Step 2: cirrus clouds (that produce little or no rainfall BUT are cold in the IR data) are at least partially eliminated using a slope parameter, and Step 3: a rainfall rate is assigned to the rain-producing coldest IR tops using a 1-D cloud model. As a result of the automatic estimates, the meteorologist can "zero in" on the potential flash flood producing MCSs and compute the more accurate interactive estimates.

Interactive Flash Flood Analyzer (IFFA) Estimates
(Scofield, 1987 and Scofield, et al., 1980)

The IFFA allows the meteorologist to be directly involved in the decision making process. The IFFA technique is a decision tree that has three basic steps: Step 1: the active portion of the MCS is located, Step 2: the half-hourly rainfall rate is computed from the following observations: (a) cloud-top temperature and cloud growth or divergence aloft and low-level inflow, (b) overshooting tops, (c) mergers, (d) stationary storms, and (e) speed of storms and Step 3: the rainfall estimates are adjusted according to the available moisture. Additional information about the satellite rainfall estimation program of NOAA/NESDIS can be obtained from Borneman, 1988 and Clark and Borneman, 1984. As mentioned at the beginning of this section, rainfall observations and radar estimates are integrated with the satellite estimates to evaluate how much rainfall has fallen and where. Now the forecaster is ready to proceed to the final Step and produce a QPF.

Step 4: Produce 0-12 Hour Quantified Precipitation Forecasts (QPFs)
(NMC flash flood course material)

In Step 4, the forecaster has to use intuition and past experiences to produce a 0-12 hour QPF. The "tools" for achieving a successful 0-12 hour QPF are: (a) conceptual models, (b) empirical rules, and (c) objective numerical and statistical forecast model guidance.

Eventually, we hope to have automatic "persistence, extrapolation and trend techniques" using observations of MCSs in the satellite and radar data (Moses, 1981). THIS ENDS THE TECHNIQUE FOR NOWCASTING HEAVY RAINFALL WHEN THE MCS IS PRESENT.

In those situations when the MCS is not present (see Figure 1), there are 3 steps to the NOWCASTING technique.

Step 1: Forecast Initial Development
(Purdom, 1986)

Step 1, shown in Figure 2, involves analyzing environmental conditions favorable for MCS initiation and development. This necessitates synoptic and mesoscale analyses. Of course, the presence and strength of any "capping inversion" or "lid" must be taken into account in order to determine the upward vertical motion (forcing mechanisms) required to remove this inversion. Bothwell's (1988) lid strength analysis is available on AFOS. Environmental conditions producing upward vertical motion range from weak to strong forcing situations. Usually, major flash flood producing MCSs result from "strong forcing" environmental conditions. An extremely important but difficult environmental interaction to anticipate and predict is the "Convective Scale Interaction". Convective Scale Interaction can cause a weak forcing situation to become a strong forcing one that produces flash floods. Convective Scale Interaction can also cause a strongly forced MCS event to persist longer than expected. As a result, extremely heavy rainfall amounts can occur.

Step 2: Forecast MCS Propagation and Step 3: Produce 0-12 hour QPFs have already been discussed. THIS ENDS THE TECHNIQUE FOR NOWCASTING HEAVY RAINFALL WHEN THE MCS IS NOT INITIALLY PRESENT.

3. AN EXAMPLE OF A BACKWARD PROPAGATING MCS ON MAY 9, 1989

As mentioned previously, backward propagating MCSs are associated with many "flash flood" producing MCSs. A backward propagating MCS is shown in Figures 3a,b,c and d. At 2200 GMT, a MCS (at C) moved into the eastern half of Arkansas. By 0100 GMT, the coldest tops were in the extreme northwest portion of the MCS (at B) and formed a "node-type" pattern; another smaller MCS (at W) developed in extreme northwest Arkansas. This "node-type" of pattern is typical of backward propagating/back building MCSs. A merger occurred at (M) (0300 GMT) between the MCSs at (B) and (W) (Figure 3c). Extremely cold tops mark the area of the merger where over eight inches of rain fell.

A SCHEME FOR NOWCASTING HEAVY RAINFALL FROM MESOSCALE CONVECTIVE SYSTEMS (MCSs)

MCS PRESENT

Step 1: Determine type of MCS present:
- MCC
- warm top
- linear
- circular/oval
- synoptic scale cyclonic circulation
- super cell

Step 2: Forecast MCS Propagation:
"Assess environmental conditions for type of MCS propagation"
- forward
- backward
- regenerative

Step 3: Compute Rainfall Estimates
- interactive
- automatic

Step 4: Produce "0 - 12 Hour" Quantified Precipitation Forecasts (QPFs)
- numerical model guidance
- empirical rules
- conceptual models
- automatic "persistence, extrapolation and trend" techniques

STOP

MCS IS NOT PRESENT

Step 1: Forecast Initial Development:

"Assess environmental conditions for MCS development"
- weak forcing
- strong forcing
- convective scale interaction
- super cell

Step 2: Forecast MCS Propagation

Step 3: Produce "0 - 12 Hour" QPFs

STOP

Figure 1. A Technique for NOWCASTING Heavy Rainfall from Mesoscale Convective Systems (MCSs).

WEAK FORCING

STRONG FORCING

Determine The Presence and Strength of Any "Capping Inversion "or "Lid"

CONVECTIVE SCALE INTERACTION

MECHANISMS (Weak Forcing)

DIFFERENTIAL HEATING:

- o SEA BREEZE
- o LAKE AND RIVER BREEZES
- o MOUNTAIN AND VALLEY BREEZES
- o FOG AND STRATUS (ESPECIALLY IN THE MORNING)

MECHANISMS (Convective Scale Interaction)

- o OUTFLOW BOUNDARIES
- o MERGING BOUNDARIES (MESOSCALE WITH MESOSCALE; MESOSCALE WITH SYNOPTIC SCALE)
- o INTERACTION WITH HIGH EQUIVALENT POTENTIAL TEMPERATURE (OR WET BULB POTENTIAL) AIR

MECHANISMS (Strong Forcing)

LOW LEVEL:

- o BOUNDARIES: (MESOSCALE/ SYNOPTIC)
- o WARM AIR ADVECTION
- o VORTICES (MESOSCALE/ SYNOPTIC)
- o INSTABILITY ADVECTION
- o LOW-LEVEL JET
- o MESOSCALE PRESSURE PULSES

MIDDLE LEVEL:

- o VORTICITY CENTERS/ POSITIVE VORTICITY ADVECTION
- o THERMAL TROUGH

UPPER LEVEL:

- o JET STREAK

SUPER CELL/SQUALL LINE

- o MCC/MCS MOVES TO RIGHT OF THE MEAN WIND
- o VERTICAL WIND SHEAR PRESENT (VEERING WITH HEIGHT)
- o INSTABILITY PRESENT
- o BULK RICHARDSON'S NUMBER LESS THAN "50"

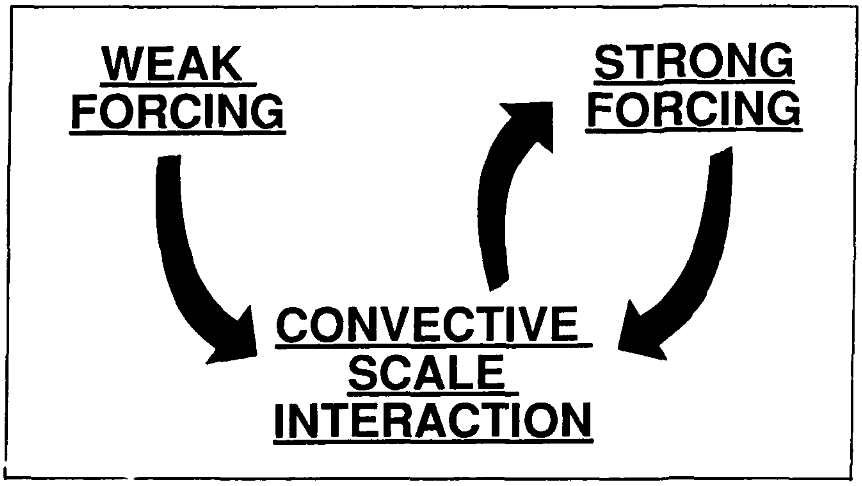

Figure 2. A Checklist for Analyzing Environmental Conditions Favorable For MCS Initiation and Development.

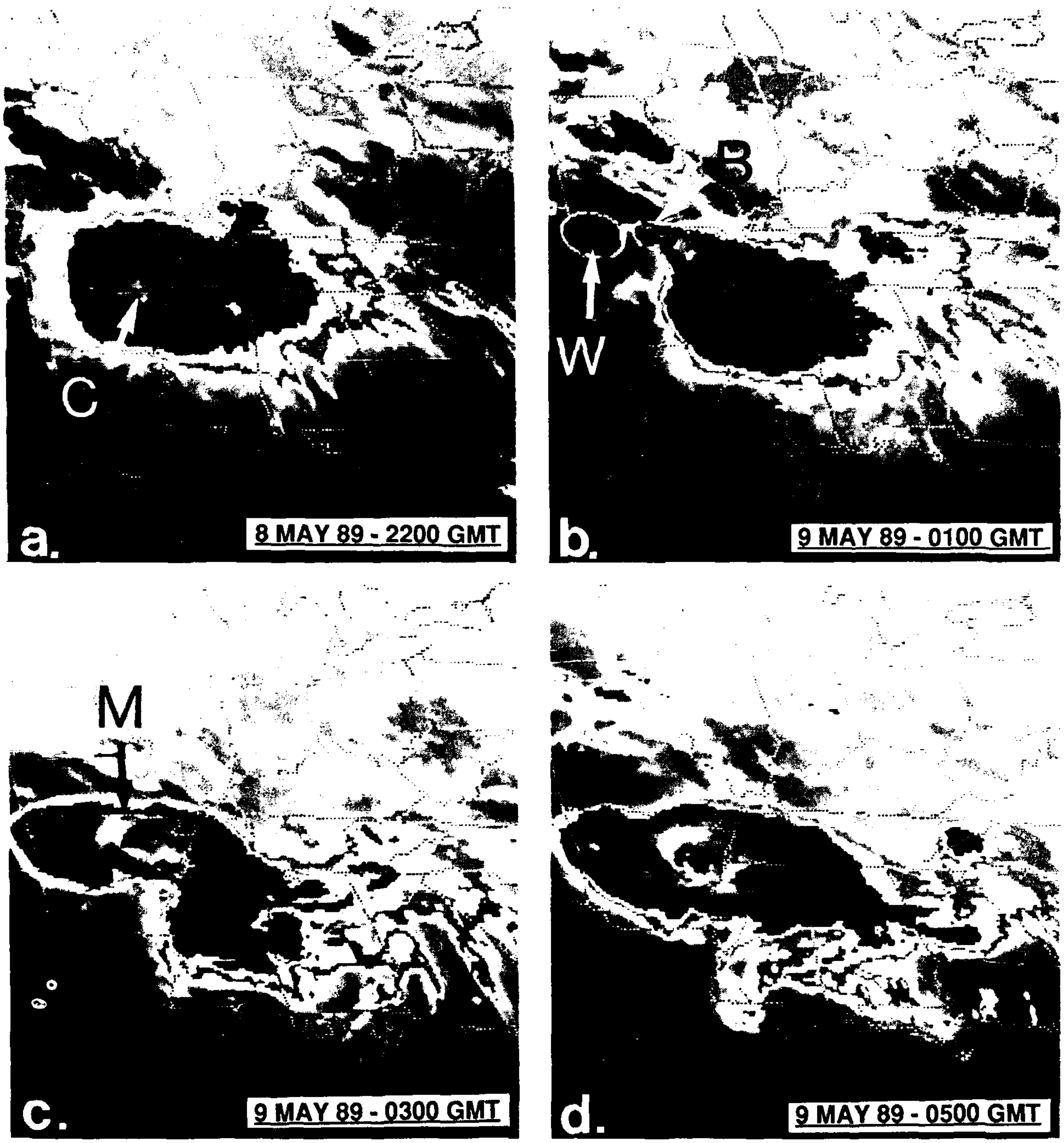

Figure 3. Enhanced IR Imagery (MB Curve), May 8 - 9, 1989.

The merger also resulted in a westward (backward) movement of the MCS (Figures 3b,c,d). Surface and upper air data (not shown) indicated that the MCS in eastern Arkansas propagated backwards along a frontal boundary towards: higher theta-e values, lower instability and maximum low level winds. The MCS also propagated backwards towards an area of 1000-500 mb thickness diffluence; the middle-upper level jet stream was located north of the area over Missouri. Plenty of moisture was available over Arkansas as indicated by the 1000-500 mb precipitable water and relative humidity analyses. The satellite and surface and upper air characteristics of this backward propagating MCS over Arkansas is very similar to the CONCEPTUAL MODEL OF BACKWARD PROPAGATING MCSs developed in NESDIS. This CONCEPTUAL MODEL is illustrated in Figure 4. The 24 hour rainfall analysis in Figure 5 shows heavy rain from northern Arkansas to northern Mississippi. However, as mentioned above, the heaviest rainfall of over eight inches occurred where the MCS propagated backwards and merged.

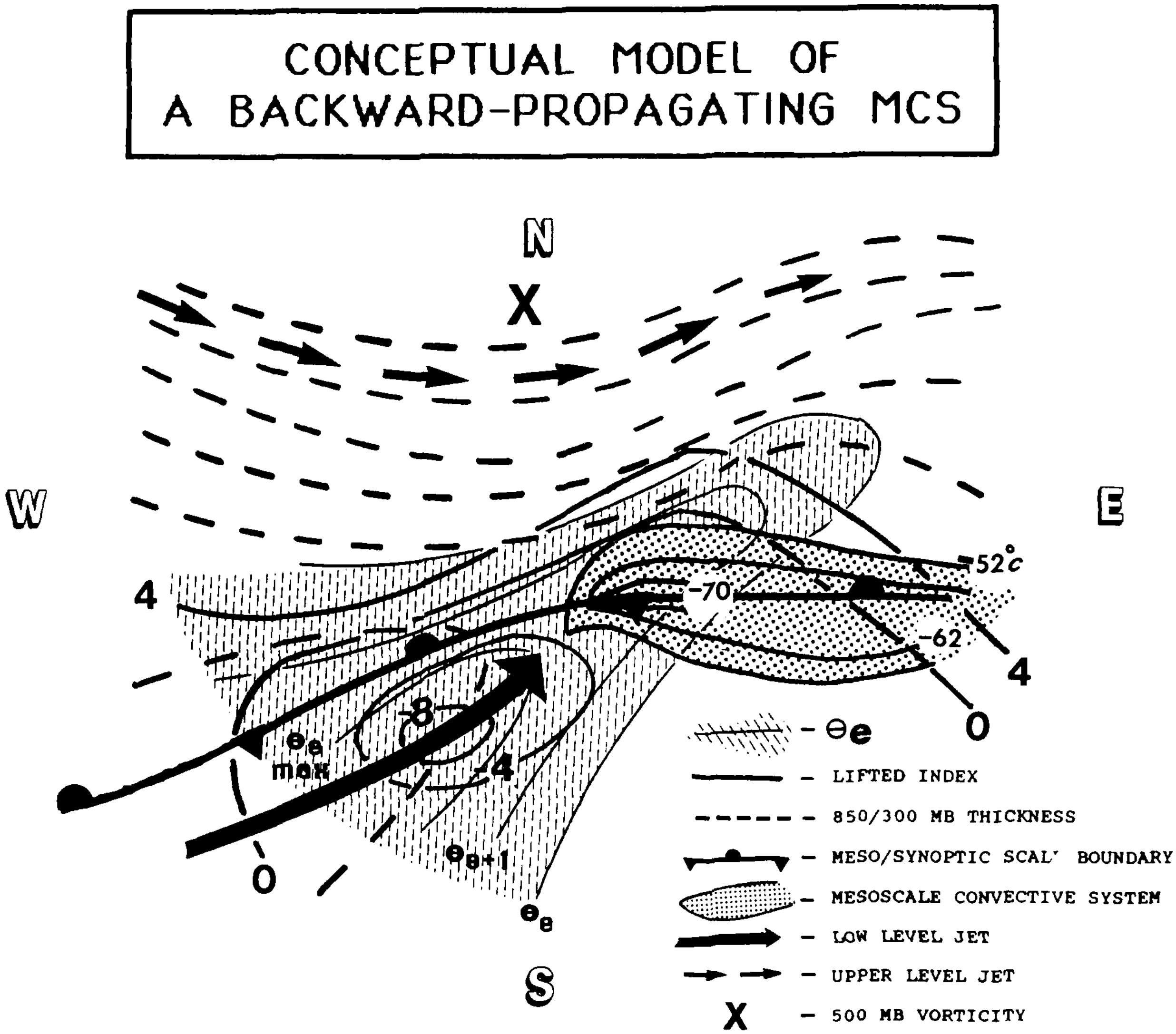

Figure 4. A Conceptual Model of a Backward-Propagating MCS.

4. OUTLOOK

PROFFENS is still being tested and undergoing development; it will take several more iterations before becoming totally operational. However, the IFFA technique and concepts from other parts of this NOWCASTING methodology are already operational. Finally, this Flash Flood NOWCASTING System, with fine tuning, will serve as a PROTOTYPE for application around the world.

5. ACKNOWLEDGMENTS

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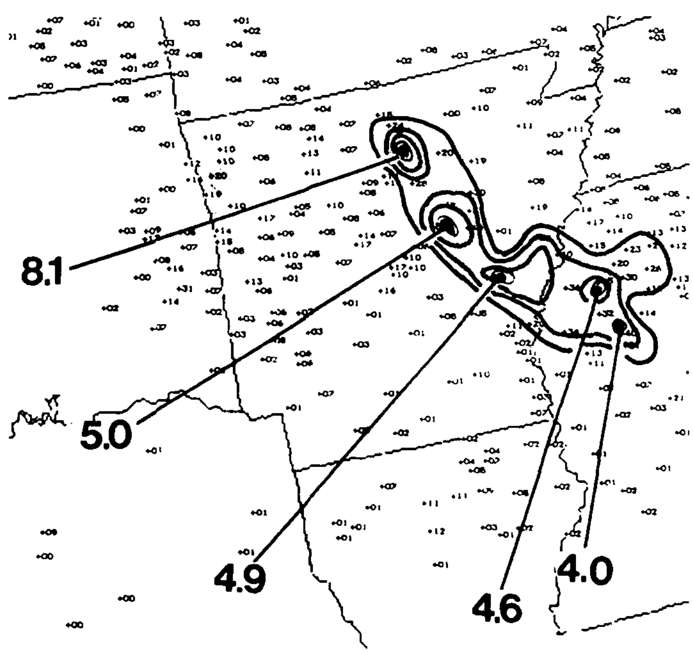

Figure 5. Twenty-Four Hour Observed Rainfall Ending at May 9, 1989, 1200 GMT.

6. REFERENCES

Adler, R.F. and A. Negri, 1988: A satellite infrared technique to estimate tropical convective and stratiform rainfall. J. Appl. Meteorology, 27, 31-51.

Borneman, R., 1988: Satellite rainfall estimating program of the NOAA/NESDIS Synoptic Analysis Branch. Nat'l. Wea. Dig., 13 (2), 9-10.

Bothwell, P.D., 1988: Forecasting convection with the AFOS data analysis programs (ADAP-Version 2.0). NOAA Technical Memorandum NWS SR 122, U.S. Dept. of Commerce, Washington, DC, 92 pp.

Clark, D. and R. Borneman, 1984: Satellite precipitation estimation program of the Synoptic Analysis Branch. Proc. of the 10th Conf. on Weather Forecasting and Analysis, June 25-29, 1984, Clearwater Beach, FL, AMS, Boston, MA, 392-399.

Juying, Xie and R.A. Scofield, 1989: Satellite-derived rainfall estimates and propagation characteristics associated with mesoscale convective systems (MCSs). NOAA/NESDIS Technical Memorandum NESDIS 25, U.S. Dept. of Commerce, Washington, DC, 49 pp.

Lyles, N. and R.A. Scofield, 1989: Rainfall estimates using the convective-stratiform technique. Proc. of the 12th Conf. on Weather Analysis and Forecasting, October 2-6, 1989, Monterey, CA, AMS, Boston, MA, 524-530.

Moses, J.F., 1981: Convective cloud tracking techniques for estimating precipitation from geostationary imagery. Proc. of the 4th Conf. on Hydrometeorology, October 7-9, 1981, Reno, NV, AMS, Boston, MA, 151-158.

NMC material presented at the NWS Flash Flood Forecasters Course in Kansas City, NWS Technical Training Center.

Purdom, J.F.W., 1986: Satellite contributions to convective scale weather analysis and forecasting. Proc. of the 11th Conf. on Weather Forecasting and Analysis, June 17-22, 1986, Kansas City, MO, AMS, Boston, MA, 295-314.

Scofield, R.A. and C.E. Weiss, 1977: A report on the Chesapeake Bay Region NOWCASTING experiment. NOAA/NESS Technical Memorandum 94, U.S. Dept. of Commerce, Washington, DC, 52 pp.

Scofield, R.A., V.J. Oliver, and L.E. Spayd, Jr., 1980: Estimating rainfall from thunderstorms with warm tops in the infrared imagery. Proc. of the 8th Conf. on Weather Forecasting and Analysis, June 10-13, 1980, Denver, CO, AMS, Boston, MA, 85-92.

Scofield, R.A., 1985: Satellite convective cloud categories associated with heavy rainfall. 1985 NWS Southern Region QPF Workshop, NOAA/NWS Technical Memorandum SR-112, 67-74.

Scofield, R.A., 1987: The NESDIS operational convective precipitation estimation technique. Mon. Wea. Rev. 115, 1773-1792.

Scofield, R.A. and J. Robinson, 1989: Instability bursts and mesoscale convective system development and propagation. Satellite Applications Information Note 89/2, NESDIS, Washington, DC.

Scofield, R.A., J. Robinson, and N. Lyles, 1990: Satellite estimates and forecasts of heavy rainfall from Mesoscale Convective Systems (MCSs). Proc. on Operational Precipitation Estimation and Prediction, February 7-8, 1990, Anaheim, CA, AMS, Boston, MA, 24-31.

Shi, Jiang and R.A. Scofield, 1987: Satellite observed Mesoscale Convective Systems (MCSs) propagation characteristics and a 3-12 hour heavy precipitation forecast index. NOAA/NESDIS Technical Memorandum 20, U.S. Dept. of Commerce, Washington, DC, 43 pp.